(19) Europäisches Patentamt
European Patent Offic
Office européen des br v ts

(11) EP 0 518 111 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
09.04.1997 Bulletin 1997/15

(51) Int Cl.6: **G02B 5/30**, G02B 27/28, H04N 9/31

(21) Application number: **92108796.1**

(22) Date of filing: **25.05.1992**

(54) **Projection image display system**

Bildprojektions-System

Système de projection d'images

(84) Designated Contracting States:
DE FR GB NL

(30) Priority: **29.05.1991 JP 124312/91**

(43) Date of publication of application:
16.12.1992 Bulletin 1992/51

(73) Proprietor: **MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.**
Kadoma-shi, Osaka-fu, 571 (JP)

(72) Inventors:
- **Miyatake, Yoshito**
  Neyagawa City 572 (JP)
- **Sannohe, Shinya**
  Osaka City 535 (JP)

(74) Representative: **Jung, Elisabeth, Dr. et al**
Patentanwälte,
Dr. Elisabeth Jung,
Dr. Jürgen Schirdewahn,
Claus Gernhardt,
Postfach 40 14 68
80714 München (DE)

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- **PATENT ABSTRACTS OF JAPAN vol. 14, no. 94 (P-1010) 21 February 1990 & JP-A-13 02 385**
- **PATENT ABSTRACTS OF JAPAN vol. 10, no. 268 (E-436) 12 September 1986 & JP-A-61 090 584**

Description

FIELD OF THE INVENTION AND RELATED ART STATEMENT

1. FIELD OF THE INVENTION

The present invention generally relates to a projection image display system comprising a polarizer, in particular such a polarizer that emits a linearly polarized light or a substantially linearly polarized light upon an incidence of a substantial natural light.

2. DESCRIPTION OF THE PRIOR ART

It has hitherto been known such a projection display system that an optical image corresponding to a video signal and produced on a light valve is projected on a projection screen. In order to produce a large screen image, the optical image on the light valve is usually magnified by a projection lens. Recently, such a projection display system that utilizes a liquid-crystal display device as light valve is attracting attention.

An example of the conventional image projection display system that utilizes the liquid-crystal display device is schematically illustrated in FIG. 9. In the system of FIG. 9, light emitted from a light source 1 is transmitted through a liquid-crystal display device 2 and is incident upon a projection lens 3. The liquid-crystal display device 2 comprises a liquid crystal cell 4, an incident side polarizing plate 5 and an output side polarizing plate 6. The liquid crystal cell 4 includes a pair of parallelly disposed glass substrates 7 and 8 and a layer 9 of twisted nematic liquid crystal sealed therebetween. On the surfaces of the glass substrates 7 and 8 facing with the liquid crystal layer 9, there are provided transparent pixel electrodes arranged in a matrix. The polarization axis of the incident side polarizing plate 5 is arranged at a right angle with that of the output side polarizing plate 6. In case where no voltage is applied across the transparent pixel electrodes, the transmittance of the liquid crystal device 2 is in its maximum because the linearly polarized light emitted from the incident side polarizing plate rotates by 90° in the liquid crystal cell 4 due to its optical rotatory power. When a voltage is applied across the transparent electrodes, the optical rotatory power decreases in response to the applied voltage, and the transmittance is reduced accordingly. In this manner, an optical image which corresponds to the video signal is produced in the liquid-crystal display device 2 as a variance in the transmittance, and this optical image is magnified by the projection lens 3 and projected on a screen 10.

In the conventional apparatus configured as shown in FIG. 9, the transmittance of the incident side polarizing plate 5 for natural light is about 40%; and most of the light component that is not transmitted is absorbed by the polarizing plate 5 and is converted into heat. When the temperature of the incident side polarizing plate 5 rises, that of the liquid crystal cell 4 also rises by radiation. In general, the polarizing plates 5 and 6 and the liquid crystal cell 4 have only limited heat resistance and lightfastness characteristics. And because of the deterioration in the polarization ability of the polarizing plates 5 and 6 and the deterioration in the picture quality of the optical image produced by the liquid crystal cell, which deteriorations are attributable to a very intensive light irradiation, it is difficult to maintain the high picture quality of projected image for a long service time.

In order to cope with this problem of elevating temperatures, generally the liquid crystal cell 4 and the polarizing plates 5 and 6 are cooled by a known (hence omitted in FIG. 9) cooling fan. But this measure produces another problem of noise attributable to the cooling fan. The quantity of light absorbed by the incident side polarizing plate 5 can be reduced, when only a linearly polarized light is led into the incident side polarizing plate 5. Thus Gagnon et al. proposes a method of arranging a polarizing beam splitter along the optical axis and close to the light source in the United States Patent No. 4,464,018. Gagnon et al. also discloses in the United States Patent No. 4,464,019, a polarizing beam splitter that utilizes a liquid in lieu of glass in order to overcome the very high manufacturing cost of the polarizing beam splitter comprising a glass prism. However, any of the conventional polarizing beam splitters occupies a large space, and thus it is difficult to arrange compact the whole system including such beam splitter.

A countermeasure of disposing a pre-polarizer close to the light source is one that might be effective. Since the pre-polarizer need not have such a high polarization efficiency as needed for the incident side polarizing plate, Ono has disclosed in Japanese Unexamined Patent Publication (Tokkaisho) 63-4217, a method of employing, as its pre-polarizer, a dyestuff-type polarizing plate, which is advantageous in its heat resistance and lightfastness characteristics as compared with an iodine-type polarizing plate. Although the heat generation in the incident side polarizing plate can be suppressed by employing the pre-polarizer it is difficult to embody this concept in a practical system, because the temperature of the space surrounding the light source is such a high degree as to exceed the limit of the heat resistance and lightfastness abilities of the prepolarizer. In any way, a new problem will arise when it is intended to overcome the limit imposed by the heat resistance and lightfastness abilities of the presently available incident side polarizing plate; and it has been difficult to obtain a bright projected image of high picture quality.

Further, Miyata et al. has disclosed in Japanese Examined Patent Publication (Tokko) 61-14486, a method of

employing a polarizer for infrared radiation obtained by providing protective films of thorium tetrafluoride on both sides of a potassium chloride substrate and by arranging the polarizer at such an incident angle that the reflectance of P polarized light is managed to be close to 0%. In this method, however, the employed polarizer has a low reflectance for the S polarized light, because the refractive index of the protective films is lower than that of the substrate. Thus the polarizer has an insufficient characteristics as the polarizer.

Moreover, Hansen et al. has disclosed in the United States Patent No. 3,439,968 a polarizer obtained by arranging a germanium substrate in a zig-zag configuration so that the light is made to be incident upon the polarizer at a Brewster's angle. The reflectance for the P polarized light which is incident upon the polarizer at the Brewster's angle, is 0%. But on the other hand, the reflectance for the S polarized light is not large.

Ashley et al. has disclosed in the United State Patent No. 3,765,746 another structure. The Ashley et al. structure comprises a polarizer obtained by vapor deposition of thin films of germanium on both sides of a sodium chloride substrate, and the polarizers are arranged in X-shape in a manner that the incident angle on the polarizer is a Brewster's angle for the germanium thin film. According to this disclosure, the boundary surface between the reflectance of the coated polarizer for the S polarized light is higher than that having no thin films owing to the interference effect of the thin film having a higher refractive index than that of the substrate. however, since the light is incident upon the boundary surface between the optical thin film and the substrate at the angle different from the Brewster's angle, the reflectance of the P polarized light is not 0%. As a result, the transmittance for the P polarized light becomes insufficient.

DE-A-974 318 discloses a polarizer in which incidence of light is made oblique with respect to a transparent substate having thereon optical thin films made of a material of high refractive index.

US-A-2 982 178 relates to a polarizing structure in which incidence of light is made oblique with respect to the transparent sheet having thin films on the faces thereof. The thin films have a high refractive index.

OBJECTS AND SUMMARY OF THE INVENTION

It is therefore a primary object of the present invention to provide a projection display system with a polarizer of low manufacturing cost and compact in size and capable of displaying a bright projected image of high picture quality for long time by employing said polarizer as its component.

According to the present invention, there is provided a projection display system comprising:

a light source for emitting light,
a polarizer for extracting a substantially linearly polarized light from the light emitted from said light source,
at least one light valve for producing an optical image in response to video signals therein, having a polarizing plate at least at its incident side, and
a projection lens capable of magnifying the optical image produced in said light valve and projecting it onto a projection screen;
wherein said polarizer comprises at least one polarization-selective mirror, which includes; a glass substrate and optical thin films having a higher refractive index than that of said glass substrate and being deposited on both the surfaces of said substrate, said polarization-selective mirror being obliquely arranged with respect to the optical axis of the system in a manner that a transmittance of the polarizer for P polarized light being incident upon the polarizer along said optical axis is of its maximum value; and said system is configured in a manner that the output light from said polarizer can travel through said incident side polarizing plate at its approximately maximum transmittance.

In the above-defined projection display system, said light valve may be a liquid-crystal display device, which comprises; a half wave plate disposed adjacent to its incident side polarizing plate; the direction of the polarization axis of said incident side polarizing plate is preferably selected to a specified angle (e.g. 45° or 0° or 90°) with respect to the vertical direction of the image; said polarizer is configured in a manner that the plane containg both the normal of the glass substrate and the optical axis is parallel to the vertical direction or the horizontal direction of the image; and said half wave plate is disposed in a manner that the light emitted from said polarizer can travel through said incident side polarizing plate at its approximately maximum transmittance.

In the above-defined projection display system, said light source preferably is capable of emitting a light containing three primary color light components, and said system further comprises;

a color separator capable of decomposing the output light emitted from said polarizer into three primary color light components, and
three light valves, each for producing an optical image in response to video signal therein, having a polarizer at least at its incident side.

Further, in the above-defined projection display systems, optical axes of lights passing through respective centers of pictures of the light valves preferably travel on the same plane, and that plane of polarization of linearly polarized light emitted from the polarization-selective mirror is preferably perpendicular to the above-mentioned same plane. Thereby, a clear projected image is obtainable by decrease of undesirable refractions of light.

By depositing the optical thin films on both the surfaces of the substrate, the polarizer used in the present invention has succeeded in improving its overall transmittance for the S polarized light, much lower than the transmittance for the S polarized light for each of either surface of the polarizer. The thus configured polarizer including at least one polarization-selective mirror can extract a light which is almost close to a linearly polarized light from natural light. When this polarizer is employed in embodying a projection image display system including polarizing plates, the reliability of the incident side polarizing plate can be improved, because the absorption quantity of light by the incident side polarizing plate can be reduced.

While the novel features of the present invention are set forth particularly in the appended claims, the invention, both as to organization and content, will be better understood and appreciated, along with other objects and features thereof, from the following detailed description taken in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG.1 is a graph representing the reflectance versus the incident angle characteristics of the polarization-selective mirror built in accordance with the present invention.

FIG.2 is a partly cut-out perspective view showing one embodiment of the polarizer built in accordance with the present invention.

FIG.3 is a schematic view showing the structure of the polarization-selective mirror.

FIG.4 is a graph showing a spectral transmittance of the polarizer built in accordance with the present invention.

FIG.5 is a schematic view showing the structure of another embodiment of the polarizer built in accordance with the present invention.

FIG.6 is a perspective view showing one embodiment of the projection display system built in accordance with the present invention.

FIG.6A is a schematic view showing operation of the pre-polarizer which is used in the embodiment in FIG.6.

FIG.7 is a perspective view showing another embodiment of the projection display system built in accordance with the present invention.

FIG.8 is a schematic view showing a further embodiment of the projection display system built in accordance with the present invention.

FIG. 9 is a schematic view showing a structure of the conventional projection display system.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[Principle]

First, the principle of the present invention will be described in the following several paragraphs.

In case where a polarized light is obliquely incident from air upon a glass substrate through an optical thin film, it is easy for understanding its reflectance to consider both reflectance R_S for S polarized light and reflectance R_P for P polarized light. The definition of S polarized light and P polarized light is light whose vibrations are perpendicular and parallel to the plane of incidence, respectively. They can be represented by the following formulae:

$$R_S = \frac{r_{S1}^2 + r_{S2}^2 + 2r_{S1}r_{S2}\cos\gamma}{1 + r_{S1}^2 r_{S2}^2 + 2r_{S1}r_{S2}\cos\gamma} \tag{1}$$

$$R_P = \frac{r_{P1}^2 + r_{P2}^2 + 2r_{P1}r_{P2}\cos\gamma}{1 + r_{P1}^2 r_{P2}^2 + 2r_{P1}r_{P2}\cos\gamma} \tag{2}$$

$$r_{S1} = \frac{n_0\cos\theta_0 - n_1\cos\theta_1}{n_0\cos\theta_0 + n_1\cos\theta_1} \tag{3}$$

$$r_{S2} = \frac{n_1\cos\theta_1 - n_2\cos\theta_2}{n_1\cos\theta_1 + n_2\cos\theta_2} \tag{4}$$

$$r_{P1} = \frac{n_0/\cos\theta_0 - n_1/\cos\theta_1}{n_0/\cos\theta_0 + n_1/\cos\theta_1} \tag{5}$$

$$r_{P2} = \frac{n_1/\cos\theta_1 - n_2/\cos\theta_2}{n_1/\cos\theta_1 + n_2/\cos\theta_2} \tag{6}$$

$$\gamma = \frac{4\pi n_1 d\cos\theta_1}{\lambda}. \tag{7}$$

In the above-mentioned formulae, r_{S1}, r_{S2}, r_{P1} and r_{P2} are reflection coefficients of the boundary surfaces formed between the optical thin films and the substrate, wherein a mark with the suffix S represents that it is for the S polarized light, that with the suffix P represents that it is for the P polarized light, that with the suffix 1 represents that it is for the boundary surface between the exterior medium and the optical thin film, and that with the suffix 2 represents that it is for the boundary surface between the optical thin film and the glass substrate, respectively. Further, d represents the film thickness of the optical thin film and λ represents the main wavelength of the light traveling through the air. Further, n_0 represents the refractive index of the exterior medium, n_1 represents the refractive index of the optical thin film and n_2 represents the refractive index of the glass substrate. θ_0 represents an angle at which the light is incident from the exterior medium upon the optical thin film, θ_1 represents an angle of refraction of the light in the optical thin film, and θ_2 represents an angle of refraction of the light in the glass substrate.

The incident angle θ_0 and angles of refraction θ_1 and θ_2 are the angle of incident light and angle of refracted light measured from the normal to the surfaces.

Among the above-stated refractive indices and angles of refraction, the following relationship holds based on Snell's law:

$$n_0\sin\theta_0 = n_1\sin\theta_1 = n_2\sin\theta_2. \tag{8}$$

Based on the foregoing formulae, it is appreciated that R_S and R_P are the functions of $\sin^2(\gamma/2)$ when the incident angle θ_0 is given and will take different values depending upon the film thickness d and the wavelength λ. Provided that the exterior medium is air ($n_0 = 1$) and that $n_1 > n_2$. R_S and R_P exist in the area between the two curves (Hatched area), respectively as shown in FIG.1. Out of the two sets of curves, the one set represents the case of $\sin^2(\gamma/2) = 1$, while the other set represents the case of $\sin^2(\gamma/2) = 0$. The latter set of curves equal to the reflectance at the surface of the substrate having no optical thin film.

The two curves of R_P become 0% at incident angles θ_A and θ_B, respectively, and cross each other at an incident angle θ_C. From FIG.1, it is appreciated that an incident angle θ_0 which makes R_P minimum resides between θ_A and θ_B when the thickness of the optical thin film is given, and that in the range of $\theta_A \leqq \theta_0 \leqq \theta_B$ the reflectance R_S becomes considerably high as compared with R_P. Since the transmittance of a surface of transparent substance is obtained by subtracting the reflectance of the surface of that from 100%, an incident angle θ_0 for resulting a maximum transmittance for the P polarized light resides between θ_A and θ_B, and when: $\theta_A \leqq \theta_0 \leqq \theta_B$, the transmittance for the P polarized light becomes nearly 100% whereas the transmittance for the S polarized light becomes considerably smaller than 100%. Further, in order to obtain a high value of the reflectance R_S, it is desirable to select the incident angle θ_0 in a manner to hold the relation $\theta_C \leqq \theta_0 \leqq \theta_B$ rather than the relation $\theta_A \leqq \theta_0 \leqq \theta_C$.

From FIG.1, it is appreciated that, when the incident angle θ_0 equals to θ_B and $\sin^2(\gamma/2) = 1$, R_P becomes 0% while R_S takes a very high value. For the same condition, the following two equations are derived from the formulae (2), (5), (6) and (7):

$$\frac{n_1^2}{\cos^2\theta_1} = \frac{n_0 n_2}{\cos\theta_0\cos\theta_2} \tag{9}$$

$$d = \frac{\lambda}{4\, n_1 \cos\theta_1}\ . \qquad (10)$$

Based on the foregoing equations (8) and (9), the incident angle θ_0 from the air is represented by:

$$\sin\theta_0 = \frac{n_1}{n_0}\left\{\frac{n_1^{\,6}(n_0^{\,2}+n_2^{\,2})-n_1^{\,2}A^{1/2}-2n_0^{\,4}n_2^{\,4}}{2\,(n_1^{\,8}-n_0^{\,4}n_2^{\,4})}\right\}^{1/2} \qquad (11)$$

$$A = n_1^{\,8}\,(n_0^{\,2}-n_2^{\,2})^2 + 4\,n_0^{\,4}n_2^{\,4}\,(n_1^{\,2}-n_0^{\,2})\,(n_1^{\,2}-n_2^{\,2})\,. \qquad (12)$$

The phenomenon that R_P becomes 0% resembles to a phenomenon that R_P becomes 0% at an especial incident angle of light entering a boundary surface between two media of each-other-different refractive index. The incident angle or the angle of refraction in this case is called as Brewster's angle in general. Throughout this specification, θ_0 in the formulae (9) and (11) is to be referred to as quasi-Brewster's angle so as to discriminate it from the general Brewster's angle. By utilizing the formula (1), the R_S in the case that the conditions represented by the formulae (9) and (11) is satisfied is represented by the following formula:

$$R_S = \left(\frac{n_0^{\,2}n_2^{\,2}-n_1^{\,4}}{n_0^{\,2}n_2^{\,2}+n_1^{\,4}}\right)^2. \qquad (13)$$

When the same optical thin films are provided on both surfaces of the glass substrate, the transmittance of the S polarized light can be reduced compared with that of the boundary surface formed between the optical thin film and the glass substrate.

When the formula (13) is rearranged by substituting $n_0 = 1$, it is appreciated that the larger is the value n_1 as compared with n_2, the larger the value R_S becomes. In other words, in order to obtain a large R_S, it is recommendable to select an optical thin film having a refractive index as high as possible as compared with that of a glass substrate.

On the other hand, when n_1 is selected to be high enough for lowering the transmittance for S polarized light, the incident angle θ_0 from the air becomes large. Then, if the polarizer is configured only with a single polarization-selective mirror, the thickness of the polarizer along the optical axis becomes extremely large. Accordingly, the polarizer of the present invention is configured by arranging a plurality of the polarization-selective mirrors in a zig-zag fashion in order to decrease the overall thickness along the optical axis. As a result, the projection display system employing this polarizer can be configured compact.

In addition, as clearly appreciated from FIG.1, when the incident angle θ_0 varies in the vicinity of θ_B, R_S varies considerably. Hereupon, the polarizer comprising a plurality of polarization-selective mirrors arranged in the zig-zag fashion, the light incident obliquely upon the polarizer is divided into two components, one being $\theta_0 > \theta_B$ and the other being $\theta_0 < \theta_B$, and the substantial R_S becomes an average of the both. Thus, the polarizer of the present invention has a small dependency on the incident angle, and hence is advantageous in securing the uniformity of the brightness in the projected image.

As above-mentioned, the polarizer used in the present invention has low manufacturing cost and small thickness. Furthermore, the projection display system according to the present invention is advantageous in high picture quality of the projected image for a long service time and in its compactness of the whole system.

[Example 1 (Polarizer 1)]

FIG.2 is a partly cut-out schematic perspective view showing a structure of an embodiment of the polarization-selective mirror, which is the essential component of the polarizer used in the present invention. In FIG.2, zig-zag grooves 22 are provided inside a framework 21, and a plurality of the polarization-selective mirrors 23 are supported by the framework 21 by engaging their ends with the grooves 22 in a manner that the side view of the mirrors 23 is arranged to be a zig-zag fashion.

FIG.3 is a schematic view showing a structure of each of the polarization-selective mirrors 23. On both surfaces of a glass substrate 24, optical thin films 25 are provided. The glass substrate 24 is a sheet of float glass of the thickness: 1.1 mm. It is desirable to employ one substance having a small absorption and a high refractive index as the optical

thin films 25. The below-mentioned table 1 shows the substances together with their refractive indices available for the optical thin films 25 for visible light. It is preferable to employ one member selected from the group consisting of titanium dioxide, cerium dioxide and zinc sulfide having the highest refractive index of 2.3 as the optical thin films 25.

TABLE 1

Substance	Refractive index
Titanium dioxide (TiO_2)	2.3
Cerium dioxide (CeO_2)	2.3
Zinc sulfide (ZnS)	2.3
Ditantalum pentoxide (Ta_2O_5)	2.1
Zinc oxide (ZnO)	2.1
Hafnium dioxide (HfO_2)	2.1
Zirconium dioxide (ZrO_2)	2.0
Diindium trioxide (In_2O_3)	2.0

It is further preferable to arrange the polarization-selective mirror 23 in a manner that the incident angle θ_0 of the light entering from the air to the mirror 23 satisfies the formulae (8) and (9) and that the thickness d of the optical thin films 25 satisfies the formula (10) in the main wavelength of the light. When air is selected as the exterior medium, titanium dioxide is selected as the substance for the optical thin films 25, and float glass is selected as the material for the glass substrate 24, there are derived: n_0 = 1, n_1 = 2.3, n_2 = 1.52, θ_0 = 72.2° and θ_1 = 23.5°. When the main wavelength is selected as λ = 500 nm, there is derived: d = 59.7 nm, as summarized in Table 2. At this time, R_S = 0.718 is derived from the formula (13).

TABLE 2

θ_0 = 72.2°, λ = 500 nm,			
Components	Substance	Refractive index	Film thickness (nm)
	Air	1.0	--
Optical thin film	Titanium dioxide	2.3	59.7 nm
Substrate	Float glass	1.52	--
Optical thin film	Titanium dioxide	2.3	59.7 nm
	Air	1.0	--

FIG.4 is a graph showing the spectral transmittance characteristics of the polarization-selective mirror 23 configured as summarized in Table 2, in the case where a parallel light beam is incident upon the mirror 23. Numerals in the graph represent the incident angles of the light beam entering from the air into the optical thin film 25. In case where the incident angle θ_0 is 72.2° , i.e., the quasi-Brewster's angle, the transmittance for the P polarized light in the spectral wavelength in the air of 400 --- 700 nm is no smaller than 95% while the S polarized light is no more than 10%. Since the polarized light must travel through two optical thin films of the same composition, the overall transmittance for the S polarized light becomes very small value. In such a case where the incident angle from the air deviates from the optimum incident angle by ± 5°, the transmittance for the P polarized light is lowered without fail whereas the transmittance for the S polarized light becomes smaller as the incident angle becomes larger. Since the polarizer of the present invention has the zig-zag arranged polarization-selective mirrors, the substantial transmittance for the S polarized light may well be considered to be about 10%, which is an average value of the transmittances for the S polarized light at the incident angles within ± 5° . In order to secure the uniformity in the light intensity distribution of the light emitted from the polarizer, it is preferable to select pieces of even number of the polarization-selective mirrors 23. Otherwise, the dependency on the incident angle would become non-symmetrical in case of oblique light incidence upon the polarizer. The effect of this non-symmetricality would likely to appear on the projected image. Based on FIG. 4, it is appreciated that the polarizer shown by FIG.2 can effectively produce a light almost similar to the linearly-polarized light in case where a converging or diverging natural light is incident upon the polarizer. Strictly speaking, the produced light comprises the dominant linearly polarized light and the slight natural light.

The present inventors have confirmed based on various experiments that when the transmittance of the polarizer for the S polarized light is no larger than about 20 %, the effect of suppressing the temperature rise in the incident side polarizing plate of the polarizer can sufficiently be appreciated. In order to decrease the transmittance of the polariza-

tion-selective mirror for the S polarized light to lower value than about 20 %, $R_S \geqq 0.55$ is sufficient; and when it is taken that $n_0 = 1$ and $n_2 = 1.52$, a condition of $n_1 \geqq 2.0$ is obtained from the formula (13). As above-mentioned, it is appreciated that when either one of titanium dioxide, cerium dioxide, zinc sulfide, ditantalum pentoxide, zirconium dioxide, diindium trioxide, zinc oxide or hafnium dioxide is employed as the material for the optical thin film, both the optical characteristics and durability of the mirror are preferable.

The relations between the incident angle θ_0 and the film thickness d shown in Table 2 are those for the optimum conditions which will satisfy the equations (9) and (10). Apart from these relations, when the transmittance of the polarization-selective mirror for the P polarized light becomes above 95% and the transmittance of that for the S polarized light becomes no more than 20% in the wavelength region of 400 nm --- 700 nm, the temperature rise of the incident side polarizing plate is suppressed satisfactorily, without decreasing hardly the amount of the light passing therethrough. In such case the condition of

$$R_S \geqq 0.55 \text{ and } R_P \leqq 0.025$$

is enough, whereby the incident angle θ_0 and the film thickness d can be selected in the region shown in Table 3.

TABLE 3

Incident angle θ_0 (°)	Film thickness d (nm)
65. 4	49. 6 --- 62. 1
66. 0	47. 9 --- 67. 3
67. 0	45. 7 --- 68. 6
68. 0	43. 1 --- 70. 4
69. 0	40. 9 --- 71. 7
70. 0	38. 7 --- 73. 0
71. 0	43. 5 --- 70. 4
72. 0	47. 9 --- 67. 8
73. 0	52. 2 --- 65. 6
74. 0	56. 6 --- 63. 4
74. 9	60. 9

Therefore, in this case, the usable incident angle θ_0 in the air is as follows:

$$65.4° \leqq \theta_0 \leqq 74.9° \tag{14}$$

and the condition for the film thickness d for this case is as follows:

$$38.7 \text{ nm} \leqq d \leqq 73.0 \text{ nm}. \tag{15}$$

[Example 2 (Polarizer 2)]

In addition to the afore-mentioned example, the transmittance of the polarization-selective mirror 23 for the S polarized light can further be lowered by configuring the mirror so as to comprise a pair of mirrors 23, 23 which are arranged in parallel to each other and sandwiching a thin air layer or a thin gap 230 therebetween as shown by the schematic view of FIG. 5. In order to make the transmittance of the polarizer for the S polarized light smaller than the value of about 20 %, a condition: $R_S \leqq 0.33$ is sufficient. When it is taken that $n_0 = 1$ and $n_2 = 1.52$, a condition: $n_1 \geqq 1.7$ is obtained from the formula (13) for this case. As above-mentioned, it is appreciated that when either one of titanium dioxide, cerium dioxide, zinc sulfide, ditantalum pentoxide, zirconium dioxide, diindium trioxide, zinc oxide, hafnium dioxide, diyttrium trioxide or silicon monoxide is employed as the material for the optical thin film, both the optical characteristics and durability of the mirror are satisfactory. The larger the number of the laminated polarization-

selective mirrors is, the smaller the transmittance for the S polarized light becomes.

It is preferable to employ either one of vacuum vapor deposition or dipping method in depositing the optical thin films 25 on both surfaces of the glass substrate 24. By depositing the thin film of titanium dioxide in the dipping method, the polarization-selective mirror can be manufactured at low cost, because the dipping method is easier in operation than the vacuum vapor deposition and capable of simultaneously forming the thin films of the same film thickness on both surfaces of the glass substrate. On such a condition that tetrabutyl titanate is used as a metal compound for forming the titanium dioxide film, and the baking temperature after the dipping is selected to be 400 -- 500 °C, a transparent titanium dioxide thin film having a refractive index close to 2.3 can be obtained.

[Example 3 (Projection Display System 1)]

FIG. 6 is a schematic perspective view showing an embodiment of the projection display system in accordance with the present invention which comprises such a polarizer as its pre-polarizer. The pre-polarizer 33 is the same as that shown in FIG.2. A light source 32 comprises a lamp to emit a light and a concave mirror for condensing the light. The light travels through the pre-polarizer 33, the incident side polarizing plate 34, the liquid crystal cell 35 and the output side polarizing plate 36, and then is incident upon the projection lens 37. The polarization axis 38 of the incident side polarizing plate 34 and the polarization axis 39 of the output side polarizing plate 36 are selected to be oriented by + 45° and - 45° with respect to the vertical direction of the image, respectively. The pre-polarizer 33 is disposed apart from the incident side polarizing plate 34 in a manner that each of the joining edges 41 of the adjacent polarization-selective mirrors 23 is selected to be vertical to the polarization axis 38 of the incident side polarizing plate 34.

When a natural light 100 from the light source 32 is incident upon the pre-polarizer 33 along the optical axis 31, it emits a strong P polarized light 42 and a weak S polarized light 43 light along optical axis 31, and emits a strong S polarized light in the oblique direction 101 and 102 as shown in FIG.6A. The strong S polarized light 101 and 102 does not reach the incident side polarizing plate 34, because the incident side polarizing plate 34 is disposed apart from the pre-polarizer 33. The P polarized light 42 travels through the incident side polarizing plate 34 at its maximum transmittance, and the weak S polarized light 43 is absorbed by the incident side polarizing plate 34. In this case, the light absorption quantity by the incident side polarizing plate 34 is reduced by a great deal, and the amount of the heat generated therein is also reduced. Thus the temperature rise in the incident side polarizing plate 34 is controlled to be small. Further, the temperature rise in the liquid crystal cell 35 is also suppressed. As a result, the reliability of the incident side polarizing plate 34 and the liquid crystal cell 35 is much improved.

The polarizer unit used in the present invention can be configured to have small thickness along the light axis, because it has the polarization-selective mirrors 23 disposed in the zig-zag fashion. As a result, only little restriction is imposed in designing the whole projection display system to incorporate the polarizer unit. For instance, both of a plane mirror and the pre-polarizer 33 can be disposed between the light source 32 and the liquid crystal cell 35, and thus a compact projection display system can be designed by the use of the plane mirror.

If multi-layer film surfaces of a glass polarizing beam splitter would be made zig-zag shape, a great rise in its manufacturing cost would be introduced in general. This is because the complexity in the machining of the glass prisms as well as their joining process are necessary. In the polarizer unit used in the present invention however, its glass substrates of overwhelmingly low cost as compared with the conventionally used glass prisms are used. And thus the polarizer unit can be manufactured at a very much low cost as compared with the conventional polarizing beam splitter.

As the lamp of the projection display system, use of any of the halogen lamp, xenon lamp and metal halide lamp may be considered. But the above-stated polarizing beam splitter could not be disposed in the vicinity of the light source, because of its disadvantage that the adhesive agent used in joining the prisms would decolorize at a high temperature. Contrary to this, the polarizer unit used in the present invention can be disposed safely in a space adjacent to the light source, because the heat resistance characteristics of the glass substrate as well as of the optical thin film are satisfactory for such a design.

In the case of employing the liquid-crystal display device as a light valve, it is the general practice to arrange the incident side polarizing plate 34 and the output side polarizing plate 36 in a manner that their polarization axes 38 and 39 are oriented at either one of + 45° or - 45° with respect to vertical direction of the image 40 as shown by FIG. 6, in order to make the picture quality of the projected image bisymmetrical. In such case, the light emitted from the pre-polarizer 33 is required to travel efficiently through the incident side polarizing plate 34, and hence the pre-polarizer 33 must be obliquely arranged whereby each of the side faces of the framework 21 are disposed slanted by 45° from the vertical direction of the image 40.

[Example 4 (Projection Display System 2)]

The arrangement as shown in FIG.6 is however difficult and inconvenient for the compact design of the overall system. Thus, in order to configure the whole system compact, it is desirable for the respective side faces of the

framework 21 of the pre-polarizer 33 to orient along the vertical and horizontal directions of the image. For this purpose, it is preferable to dispose a half wave plate 430 between the pre-polarizer 33 and the incident side polarizing plate 34 and adjacent to the latter as shown in FIG.7. The linearly polarized light 44 is emitted from the pre-polarizer 33 orienting its polarization direction to the vertical direction of the image 40, and the half wave plate 430 is arranged in a manner that its fast optic axis 45 is oriented by 22.5° with respect to the vertical direction of the image 40. When the linearly polarized light 44 from the pre-polarizer 33 is incident upon the half wave plate 430, a linearly polarized light is emitted with the plane of polarization oriented by 45° with respect to the vertical direction of the image. And this linearly polarized light travels through the incident side polarizing plate 34. It is recommendable that the half wave plate 430 is disposed in a manner that the direction of its fast optic axis or its slow optic axis orients to a direction of a line in a manner that the line equally halves an angle formed between the direction of the P polarized light 44 emitted from the pre-polarizer 33 and the direction of the polarization axis 38 of the incident side polarizing plate 34. The half wave plate 430 is such a device that, when one and the other linearly polarized lights, which are each-other in the same phase and are oriented to its fast optic axis and its slow optic axis respectively, are incident upon the plate simultaneously, both the resultant lights at the output side differs in phase by a half wavelength. In the configuration of the system shown in FIG.7, it is impossible to make the phase difference a half wavelength throughout the whole wavelength, because of the wide spectrum of the light emitted from the light source 32. It however can safely be ignored as far as the practical system is designed in a manner that the phase difference at the green light spectrum region having a high spectral luminous efficiency is to be made one half wavelength.

[Example 5 (Projection Display System 3)]

FIG.8 is a schematic side view showing a structure of another embodiment of the projection display system built in accordance with the present invention. In this embodiment, the pre-polarizer unit 62 is the same as that shown in FIG. 2, and the light source 61 emits the light containing components of the three primary color lights of red, green and blue. When the light emitted from the light source 61 is via a mirror 60 incident upon the pre-polarizer 62, it emits the linearly polarized light whose plane of polarization is oriented to the vertical direction of the image. The linearly polarized light is incident upon a color separator comprising two dichroic mirrors 63 and 64, and a plane mirror 65 and is decomposed into three primary color lights. Each of the primary color lights travels through one of the field lenses 111, 112 and 113, one of the half wave plates 66, 67 and 68, one of the incident side polarizing plates 69, 70 and 71, one of the liquid crystal cells 72, 73 and 74, and one of the output side polarizing plates 75, 76 and 77, respectively. Each of the lights emitted from the output side polarizing plates 75, 76 and 77 is synthesized into a light by a color combiner comprising two dichroic mirrors 78 and 79, and a plane mirror 80 and then is incident upon the projection lens 81. In this case also, the optical system contains, in its light paths, the half wave plates 66, 67 and 68, in order to cause the lights to travel through the incident side polarizing plates 69, 70 and 71 at their maximum transmittance. The pre-polarizer 62 emits a light which is close to the linearly polarized light to reduce the absorption of the light at the incident side polarizing plates 69, 70 and 71, and accordingly the heat generation by the incident side polarizing plates 69, 70 and 71 is effectively suppressed. Further, since the pre-polarizer unit 62 can safely be disposed in the vicinity of the light source 61 by virtue of its good heat resistance characteristics and the thickness of the pre-polarizer unit 62 along the optical axis is sufficiently small, a compact design of the whole system is made possible.

In the configuration as shown in FIG.8, there is a case that the temperature of the incident side polarizing plate 70 rises extremely, because the S polarized light emitted obliquely from the pre-polarizer 62 enters the incident side polarizing plate 70. In this case, it is preferable that the pre-polarizer 62 is arranged in a manner that the joining edges 41 of the adjacent polarization-selective mirrors 23 are parallel to a plane which contains axes of lights passing through respective centers of pictures of the liquid crystal cells 72, 73 and 74 so that the S polarized light emitted obliquely from the pre-polarizer 62 cannot enter the incident side polarizing plate 70. As a result, its temperature rise can be suppressed.

The embodiment as shown in FIG.8 is a projection display system which has three liquid crystal panels and one projection lens. However, a projection display system which has three liquid crystal panels and three projection lenses is obtainable. In this system, the color combiner is not necessary; each optical image formed in the respective liquid crystal panel is magnified by each projection lens, and the image is projected and synthesized on the projection screen. The pre-polarizer as shown in FIG.2 can be used in this system.

In the foregoing embodiments, those examples wherein a liquid-crystal display device is used as the light valve are disclosed. But, any device such as electro-optic crystal may also be employed as the light valve, as far as the device is capable of producing an optical image by varying in optical rotatory power, birefringence or the like in response to the video signal, and that the device is used by combining a polarizing plate at least at its incident side.

As described in the foregoing paragraphs, according to the present invention, it is possible to provide the polarizer unit which has a small thickness and can be made with low manufacturing cost, as a result of the configuration that it comprises a plurality of the polarization-selective mirrors arranged in the zig-zag fashion in its cross-sections, and that

the polarization-selective mirrors comprise the glass substrates whose both surfaces are coated with the optical thin films. It is also possible to provide the compact projection display system of low manufacturing cost, capable of displaying the bright projected image of high picture quality for a long time, as a result of improved reliability of the incident side polarizing plate by employing the stated polarizer unit. Thus, the present invention has a great advantage.

Although the present invention has been described in terms of the presently preferred embodiments, it is to be understood that such disclosure is not to be interpreted as limiting. Various alterations and modifications will no doubt become apparent to those skilled in the art after having read the above disclosure. Accordingly, it is intended that the appended claims be interpreted as covering all alterations and modifications as fall within the scope of the claims.

Claims

1. A projection display system comprising:

   a light source (32, 61) for emitting light;
   a polarizer (33, 62) for extracting a substantially linearly polarized light from the light emitted from said light source (32, 61);
   at least one light valve (35, 72, 73, 74) for producing therein an optical image in response to video signals and having a polarizing plate (34, 69, 70, 71) at least at its incident side; and
   a projection lens (37, 81) capable of magnifying the optical image produced in said light valve (35, 72, 73, 74) and projecting it onto a projection screen;

   characterized in that

   said polarizer (33, 62) comprises
   at least one polarization-selective mirror (23) which includes: a glass substrate (24); and optical thin films (25) having a higher refractive index than that of said glass substrate (24) and being deposited on both the surfaces of said substrate (24),
   said polarization-selective mirror (23) being obliquely arranged with respect to the optical axis of the system in a manner that a transmittance of the polarizer (33, 62) for P polarized light being incident upon the polarizer (33, 62) along said optical axis (31) is of its maximum value, and
   said system is configured in a manner that the output light from said polarizer (33, 62) can travel through said incident side polarizing plate (34, 69, 70, 71) at its approximately maximum transmittance.

2. The projection display system in accordance with claim 1, wherein
   said light valve is a liquid-crystal display device.

3. The projection display system in accordance with claim 1, wherein
   the direction axis of said incident side polarizing plate (34, 69, 70, 71) is about 0°, 45° or 90° with respect to the vertical direction of the optical image produced in said light valve (35, 72, 73, 74).

4. The projection display system in accordance with claim 1 or 2, wherein

   said light valve (35, 72, 73, 74) comprises a half wave plate (43, 66, 67, 68) disposed adjacent to its incident side polarizing plate (34, 69, 70, 71), the direction of the polarization axis (38) of said incident side polarizing plate (34, 69, 70, 71) being about 45° with respect to the vertical direction of the image, and
   said polarizer (33, 62) is configured in a manner that the central plane of polarization of the approximately linearly polarized light emitted from said polarizer (33, 62) is to orient to the vertical direction or the horizontal direction of the image, and
   said half wave plate (43, 66, 67, 68) is disposed in a manner that the light emitted from said polarizer (33, 62) can travel through said incident side polarizing plate (34, 69, 70, 71) at its approximately maximum transmittance.

5. The projection display system in accordance with claim 1, 2 or 4, wherein

   said light source (61) is capable of emitting a light containing three primary color light components, and the system further comprises:
   a color separator capable of decomposing the output light emitted from said polarizer (62) into three primary

color light components, and wherein the system comprises
three of said light valves (72, 73, 74) each for producing an optical image in response to video signal therein and having a respective polarizing plate (69, 70, 71) at least at its incident side.

6. The projection display system in accordance with claim 5, wherein

axes of lights passing through respective centers of pictures of the light valves (72, 73, 74) travel on the same plane, and
a plane of polarization of the linearly polarized light emitted from the polarization-selective mirror (23) is perpendicular to the above-mentioned same plane.

7. The projection display system in accordance with claim 1, further comprising:
a framework (21) which supports a plurality of said polarization-selective mirrors (23) in zig-zag fashion, in a manner that a transmittance of the polarizer (33, 62) for P polarized light being incident upon the polarizer (33, 62) along said optical axis is to be its maximum value.

8. The projection display system in accordance with claim 7, wherein
even number of said polarization-selective mirrors (23) are supported by said framework (21).

Patentansprüche

1. Bildprojektionssystem mit:

Einer Lichtquelle (32, 61) zum Emittieren von Licht;
einem Polarisator (33, 62) zum Extrahieren eines im wesentlichen linear polarisierten Lichts, das von der Lichtquelle (32, 61) emittiert wird;
wenigstens einem Lichtventil (35, 72, 73, 74) zum Erzeugen eines optischen Bilds darin ansprechend auf Videosignale, und mit einer Polarisationsplatte (34, 69, 70, 71) wenigstens auf seiner Einfallseite; und
einem Projektionsobjektiv (37, 71), das in der Lage ist, das optische Bild zu vergrößern, das in dem Lichtventil (35, 72, 73, 74) erzeugt wird, und es auf einen Projektionsschirm zu projezieren;

dadurch gekennzeichnet, daß

der Polarisator (33, 62) aufweist:
Wenigstens einen polarisationsselektiven Spiegel (23), der ein Glassubstrat (24) und optische Dünnfilme (25) enthält, die einen höheren Brechungsindex aufweisen als derjenige des Glassubstrats (24), und die auf beiden Oberflächen des Substrats (24) abgeschieden sind,
der polarisationsselektive Spiegel (23) in bezug auf die optische Achse des Systems so schräg angeordnet ist, daß ein Lichtdurchlaßgrad des Polarisators (33, 62) für P-polarisiertes Licht, das auf dem Polarisator (33, 62) entlang der optischen Achse (31) einfällt, seinen Maximalwert aufweist, und
das System so konfiguriert ist, daß das Austrittslicht von dem Polarisator (33, 62) durch die einfallseitige Polarisationsplatte (34, 69, 70, 71) bei ihrem ungefähr maximalen Lichtdurchlaßgrad hindurchlaufen kann.

2. Bildprojektionssystem nach Anspruch 1, wobei
das Lichtventil ein Flüssigkristallanzeigeelement ist.

3. Bildprojektionssystem nach Anspruch 1, wobei
die Richtungsachse der einfallseitigen Polarisationsplatte (34, 69, 70, 71) in bezug auf die vertikale Richtung des in dem Lichtventil (35, 72, 73, 74) erzeugten optischen Bilds etwa 0°, 45° oder 90° verläuft.

4. Bildprojektionssystem nach Anspruch 1 oder 2, wobei

das Lichtventil (35, 72, 73, 74) eine Halbwellenplatte (43, 66, 67, 68) aufweist, die benachbart zu seiner einfallseitigen Polarisationsplatte (34, 69, 70, 71) angeordnet ist, wobei die Richtung der Polarisationsachse (38) der einfallseitigen Polarisationsplatte (34, 69, 70, 71) etwa 45° in bezug auf die vertikale Richtung des Bilds verläuft, und wobei
der Polarisator (33, 62) so konfiguriert ist, daß die Polarisationsmittenebene des ungefähr linear polarisierten

Lichts, das von dem Polarisator (33, 62) emittiert wird, zu der vertikalen Richtung oder der horizontalen Richtung des Bilds ausgerichtet ist bzw. auszurichten ist, und wobei
die Halbwellenplatte (43, 66, 67, 68) so angeordnet ist, daß das von dem Polarisator (33, 62) emittierte Licht durch die einfallseitige Polarisationsplatte (34, 69, 70, 71) bei ihrem ungefähr maximalen Lichtdurchlaßgrad hindurchlaufen kann.

5. Bildprojektionssystem nach Anspruch 1, 2 oder 4, wobei

die Lichtquelle (61) in der Lage ist, ein Licht zu emittieren, das drei Primärfarbenlichtkomponenten enthält, und wobei das System außerdem aufweist:
Einen Farbseparator, der in der Lage ist, das von dem Polarisator (62) emittierte Ausgangslicht in die drei Primärfarbenlichtkomponenten aufzutrennen, und wobei
das System drei der Lichtventile (72, 73, 74) aufweist, von denen jedes zum Erzeugen eines optischen Bilds ansprechend auf ein Videosignal darin ausgelegt ist und eine jeweilige Polarisationsplatte (69, 70, 71) wenigstens auf seiner Einfallseite aufweist.

6. Bildprojektionssystem nach Anspruch 5, wobei
durch jeweilige Bildmitten der Lichtventile (72, 73, 74) hindurchtretende Lichtachsen auf derselbe Ebene hindurchlaufen, und eine Polarisationsebene des linear polarisierten Lichts, das von dem polarisationsselektiven Spiegel (23) emittiert wird, senkrecht zu eben dieser Ebene verläuft.

7. Bildprojektionssystem nach Anspruch 1, außerdem aufweisend:
Einen Rahmenaufbau (21), der eine Mehrzahl von den polarisationsselektiven Spiegeln (23) in Zick-Zack-Weise so trägt, daß ein Lichtdurchlaßgrad des Polarisators (33, 62) für P-polarisiertes Licht, das auf den Polarisator (33, 62) entlang der optischen Achse einfällt, seinen Maximalwert einnimmt.

8. Bildprojektionssystem nach Anspruch 7, wobei
eine gerade Anzahl der polarisationsselektiven Spiegel (23) durch den Rahmenaufbau (21) getragen ist.

Revendications

1. Système d'affichage par projection comportant :

une source de lumière (32, 61) pour émettre de la lumière;
un polarisateur (33, 62) pour extraire une lumière polarisée essentiellement linéaire à partir de la lumière émise par ladite source de lumière (32, 61);
au moins une valve optique (35, 72, 73, 74) pour produire une image optique en réponse aux signaux vidéo et comportant une plaque de polarisation (34, 69, 70, 71) au moins sur son côté incident; et
une lentille de projection (37, 81) capable de développer l'image optique produite dans ladite valve optique (35, 72, 73, 74) et projetant celle-ci sur un écran de projection;

caractérisé en ce que :

ledit polarisateur (33, 62) comprend
au moins un miroir de polarisation sélective (23) qui comporte : un substrat de verre (24); et des films minces optiques (25) comportant un indice de réfraction plus grand que celui dudit substrat de verre (24) et étant déposé sur les deux surfaces dudit substrat de verre (24),
ledit miroir de polarisation sélective (23) étant disposé obliquement par rapport à l'axe optique du système de sorte qu'un facteur de transmission du polarisateur (33, 62) pour la lumière polarisée P incidente sur le polarisateur (33, 62) le long dudit axe optique (31) soit à sa valeur maximum, et
ledit système est configuré de sorte que la lumière sortie dudit polarisateur (33, 62) peut passer au travers de ladite plaque de polarisation de son côté incident (34, 69, 70, 71) à son facteur de transmission approximativement au maximum.

2. Système d'affichage par projection selon la revendication 1, dans lequel
ladite valve optique est un dispositif d'affichage à cristaux liquides.

3. Système d'affichage par projection selon la revendication 1, dans lequel
l'axe de direction de ladite plaque de polarisation de côté incident (34, 69, 70, 71) est d'environ 0°, 45° ou 90° par rapport à la direction verticale de l'image optique produite dans ladite valve optique (35, 72, 73, 74).

4. Système d'affichage par projection selon la revendication 1 ou 2, dans lequel

ladite valve optique (35, 72, 73, 74) comporte une plaque demi-onde (43, 66, 67, 68) adjacente à sa plaque de polarisation de côté incident (34, 69, 70, 71), la direction de l'axe de polarisation (38) de ladite plaque de polarisation de côté incident (34, 69, 70, 71) étant d'environ 45° par rapport à la direction verticale de l'image, et ledit polarisateur (33, 62) est configuré de façon à ce que le plan central de polarisation de la lumière polarisée approximativement linéairement émise à partir dudit polarisateur (33, 62) soit orienté dans la direction verticale ou la direction horizontale de l'image, et
ladite plaque demi-onde (43, 66, 67, 68) est disposée de façon à ce que la lumière émise à partir dudit polarisateur (33, 62) puisse passer au travers de ladite plaque de polarisation de son côté incident (34, 69, 70, 71) à son facteur de transmission approximativement maximum.

5. Système d'affichage par projection selon la revendication 1, 2 ou 4, dans lequel

ladite source de lumière (61) est capable d'émettre une lumière comportant trois composantes de couleur primaire, et le système comporte en outre :
un séparateur de couleur capable de décomposer la lumière sortie émise à partir dudit polarisateur (62) dans les trois composantes de couleur primaire, et dans lequel le système comporte
trois desdites valves optiques (72, 73, 74) chacune pour produire une image optique en réponse au signal vidéo, et comportant une plaque de polarisation respective (69, 70, 71) au moins sur son côté incident.

6. Système d'affichage par projection selon la revendication 5, dans lequel

des axes de lumière passant au travers des centres respectifs des images des valves optiques (72, 73, 74) courent sur le même plan, et
un plan de polarisation de la lumière polarisée linéairement émise à partir du miroir de polarisation sélective (33) est perpendiculaire au même plan mentionné ci-dessus.

7. Système d'affichage par projection selon la revendication 1, comportant en outre :
un cadre (21) qui supporte une pluralité desdits miroirs de polarisation sélective (23) en , zigzag, de manière à ce qu'un facteur de transmission du polarisateur (33, 62) pour la lumière polarisée P incidente sur le polarisateur (33, 62) le long dudit axe optique soit à sa valeur maximum.

8. Système d'affichage par projection selon la revendication 7, dans lequel
un nombre paire de 10 miroirs de polarisation sélective (23) est supporté par ledit cadre (21).

FIG.1

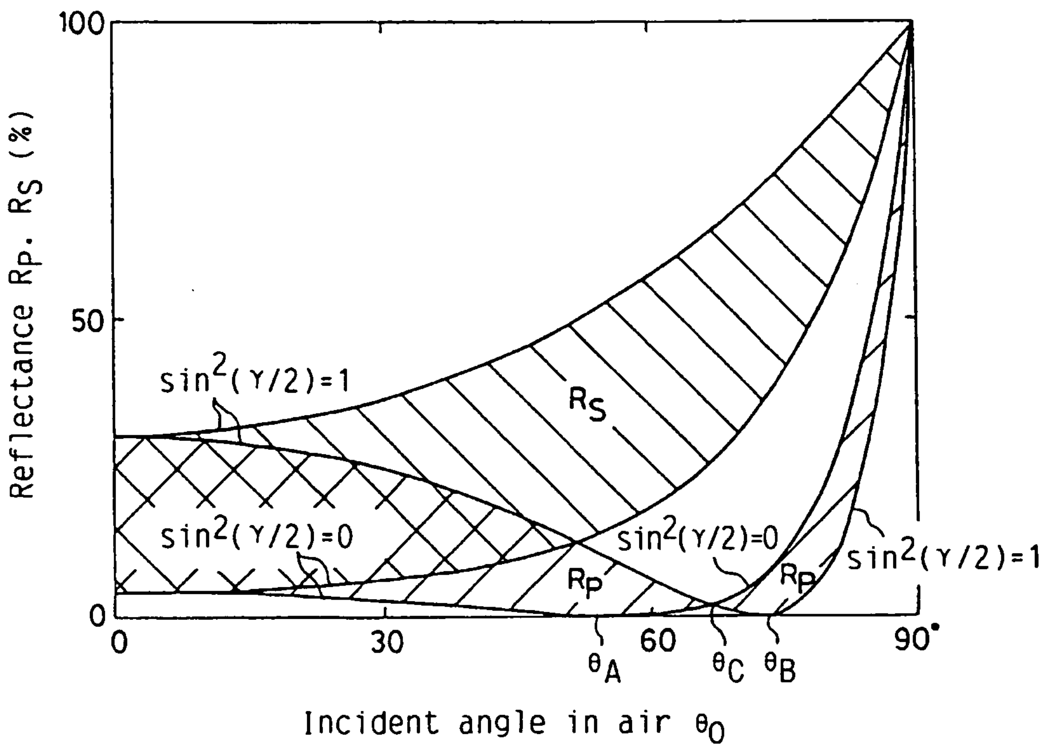
100
50
0
Reflectance Rp. Rs (%)
sin2(γ/2)=1
Rs
sin2(γ/2)=0
sin2(γ/2)=0
Rp
Rp
sin2(γ/2)=1
0
30
60
90°
θA
θC
θB
Incident angle in air θ0

FIG.2

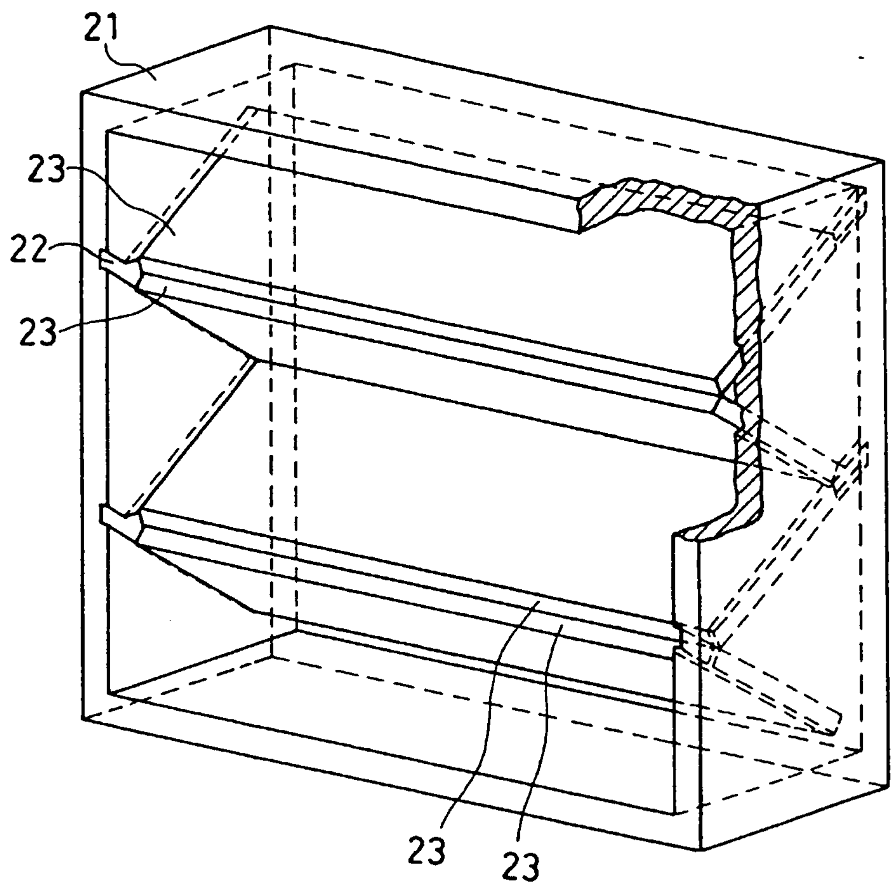

FIG. 3

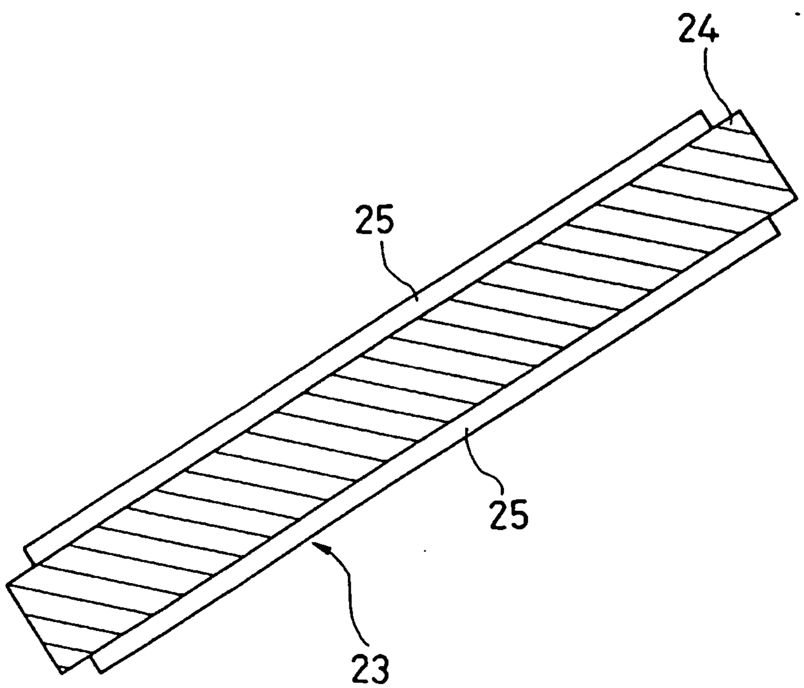

FIG. 4

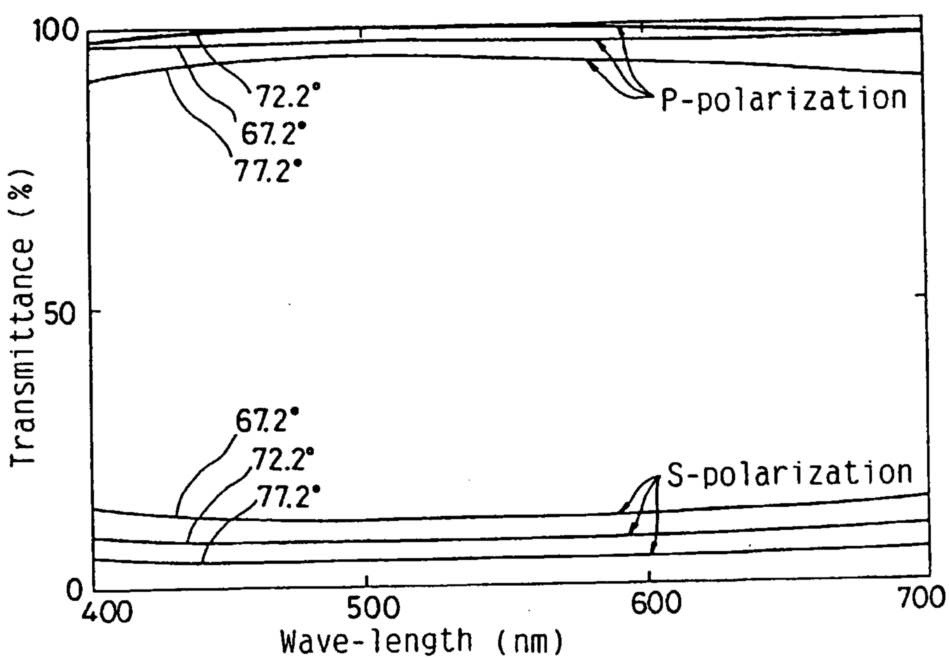
100
50
0
Transmittance (%)
400
500
600
700
Wave-length (nm)
72.2°
67.2°
77.2°
P-polarization
67.2°
72.2°
77.2°
S-polarization

FIG.5

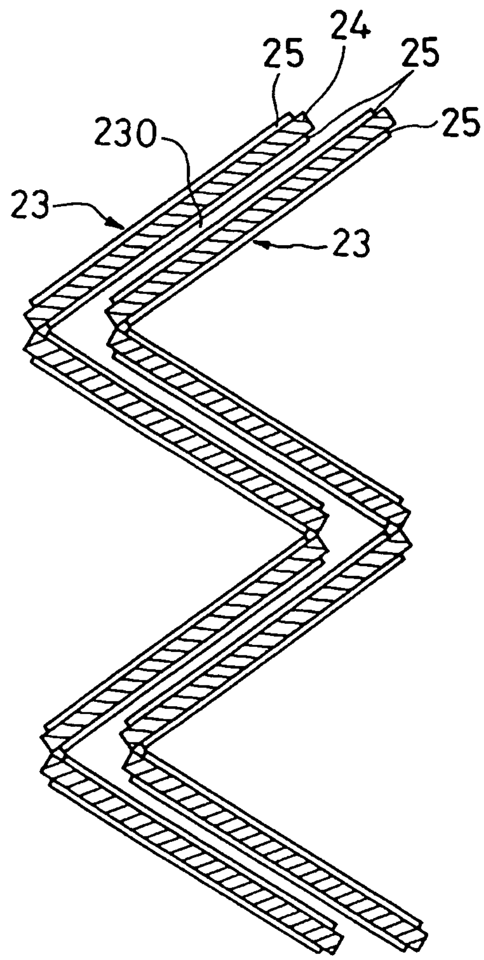

FIG. 6

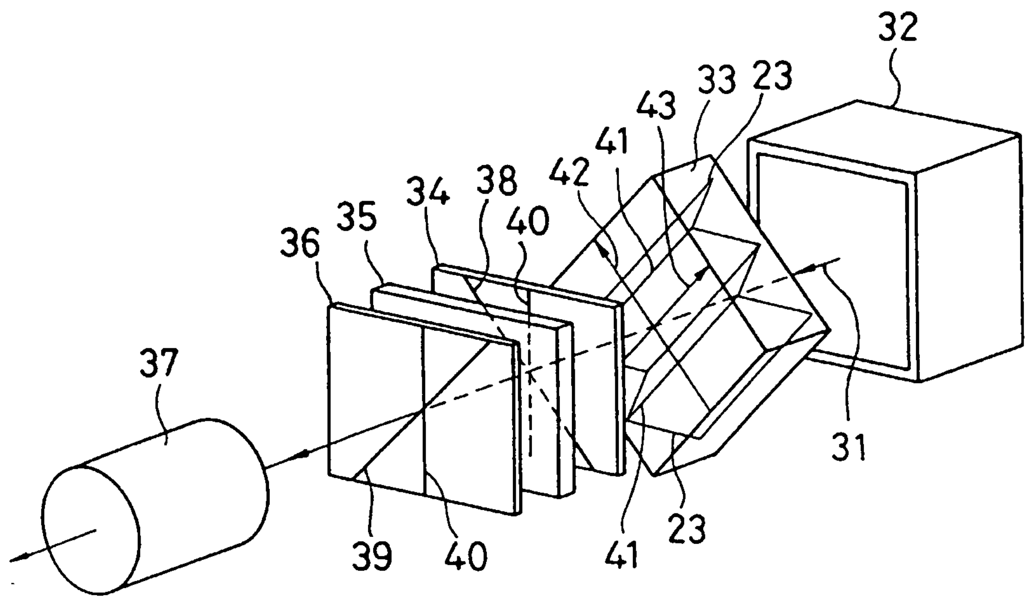

FIG. 6A

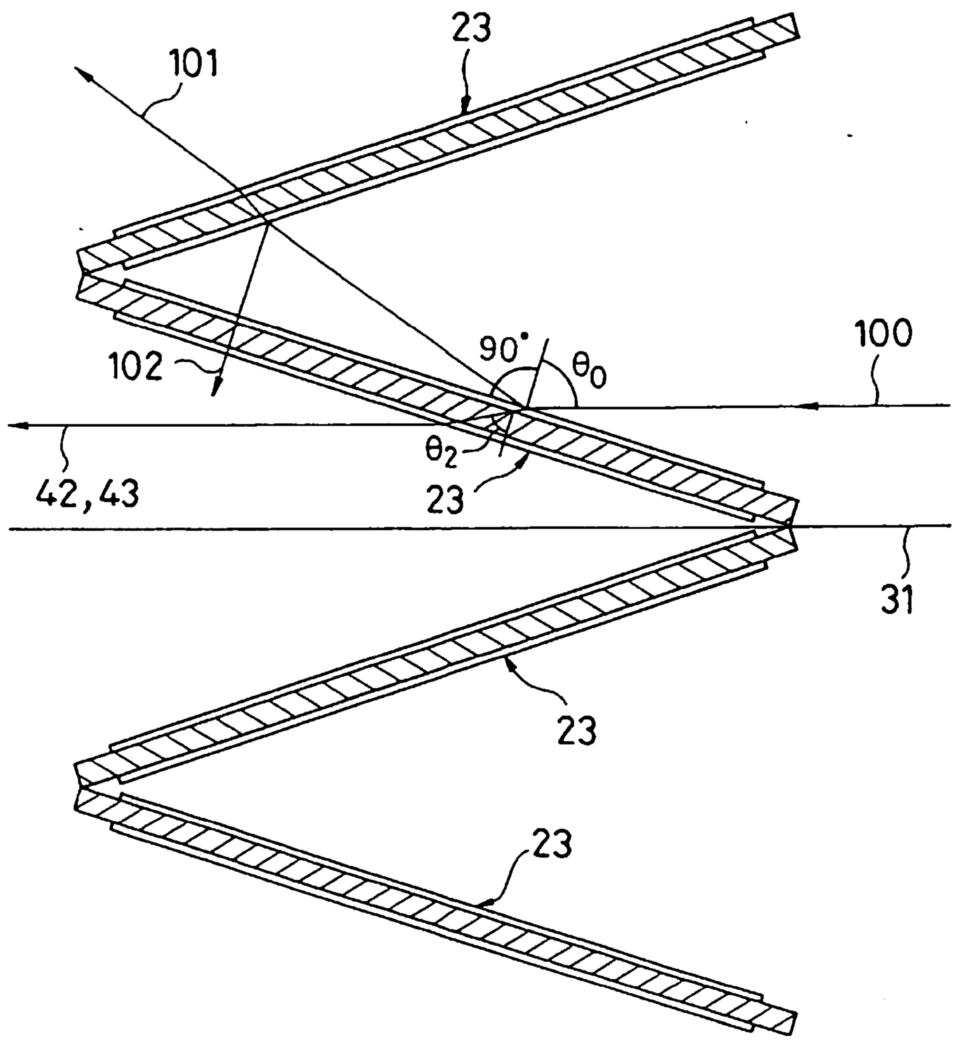

FIG. 7

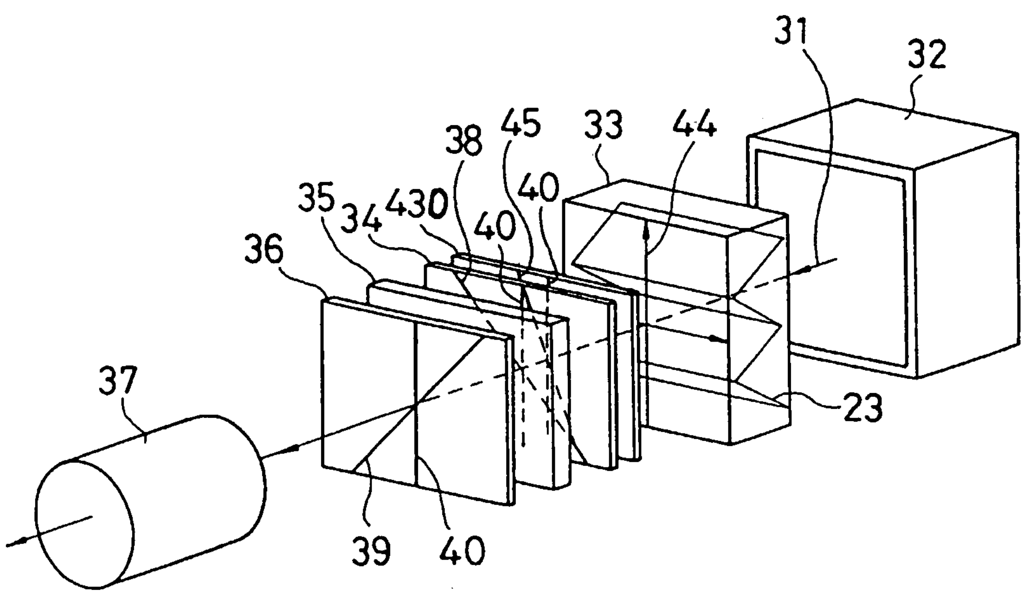

FIG. 8

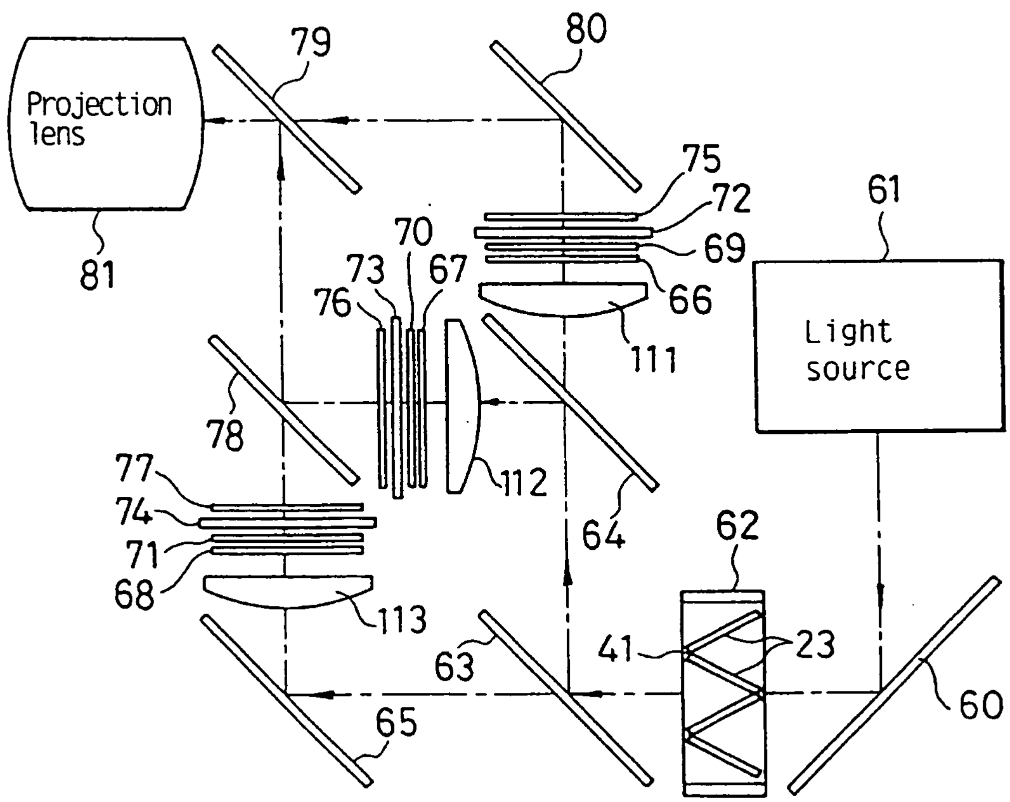
Projection lens
81
79
80
75
72
69
66
111
70
73
67
76
78
112
64
77
74
71
68
113
63
65
62
41
23
60
61
Light source

FIG.9